POTHOLES: THEIR VARIETY, ORIGIN AND SIGNIFICANCE[1]

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INTRODUCTORY—OCCURRENCE AND TERMS USED

WHERE streams have eroded channels in bed rock, hollows of characteristic shape, called "potholes," commonly appear. In ground plan potholes are typically circular or elliptical, but often deviate from this ideal shape. As a general rule such depressions are of less diameter at the top than in their middle sections or bottoms.

The term "pothole" has at various times been criticized by geologists, notably by Hershey[2] on the ground that the word "is inelegant and grates harshly on people of sensitive temperament." He suggested the use of the term "remolino," a Spanish word used in the Republic of Colombia for such hollows. Hershey's proposal elicited several comments for and against the use of this term. Farrington[3] favored the substitution, because, according to his idea, "remolino" suggested more adequately than "pothole" the manner of formation of the holes. Hilder,[4] on the other hand, pointed out that the Spanish word has several meanings, for example, "a whirlpool" or "whirlwind," and that it had even been applied to a turbulent mob of people.

In geological literature there are many articles describing "giants' kettles." These papers refer almost exclusively to that type of pothole development due to the work of glacial waters. There seems to be a paucity of articles dealing with

1 To Prof. O. D. von Engeln, at whose suggestion this investigation was begun, the writer is indebted for friendly advice and interest shown during the progress of the investigation.

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2 Hershey, O. H., "Pothole vs. Remolino," *Science*, N. S., Vol. X., p. 58, 1899.

3 Farrington, O. C., "Pothole vs. Remolino," *Science*, N. S., Vol. X., p. 187, 1899.

4 Hilder, F. F., "Pothole vs. Remolino," *Science*, N. S., Vol. X., p. 88, 1899.

potholes that have been sculptured by existing streams or that are now in process of development along such stream courses.

The primary purpose of this paper is, therefore, to describe and account for the existence of pothole hollows in the channels of existing stream courses, giving especial attention to observation of such phenomena as they occur in horizontally bedded strata composed of shales and sandstones.

Since, however, potholes have always excited considerable popular interest and as such phenomena are by no means all of the normal type to which the principal discussion refers, a review of some of the earlier literature on the origin of such depressions, together with an attempt to classify and briefly describe the several variant types, will serve to give the reader an appreciation of the broader aspects of the subject.

Early Ideas concerning Potholes

In the earlier literature, generally with reference to occurrences in glaciated regions, the terms, "giants' kettles," "giants' caldrons," "Indian kettles," "Indian mortars" and "wells," were often applied to potholes; indicating that their origin was either superstitiously ascribed to the work of giants, primarily because of their large size, or referred to the handicraft of the North American aborigines. Brögger and Reusch[5] cite several examples from Norway of fanciful notions regarding the origin of such hollows. In one instance where a large pothole excavation had been cut through by a road, the belief is that "there St. Olaf turned his horse round" and in other instances from the same region the idea prevailed, that, since occasionally the holes resemble in outline the print of a human foot, they are footprints left by giants while taking huge strides across the country. On the west coast of Norway the term "*gygre-serrer*," or "giants' chairs" is used in referring to potholes. Again, according to Brögger and Reusch,[6] one of the early writers, Neels Herzberg, had both strange and rational ideas concerning the hollows. He suggested that they were due to the power of lightning, or to the activities of a monster sea worm, of which he thought examples were perhaps still to be found in the deep, such animals having "worked them out in olden times, before the rock had hardened, just as boring mussels do in our day in a small way." Herzberg thought it

[5] Brögger, W. C., and Reusch, H. H., "Giants' Kettles at Christiania," *Quart. Jour. Geol. Soc. of London,* Vol. 30, p. 750, 1874.

[6] Brögger, W. C., and Reusch, H. H., "Giants' Kettles at Christiania," *Quart. Jour. Geol. Soc. of London,* Vol. 30, p. 762, 1874.

not impossible that potholes might be formed by ordinary raindrops during the lapse of a tremendous period of time, in the same manner that he had seen a miniature kettle hollowed out by twenty-two years' continual dropping of water on a flagstone outside his window. Although Herzberg entertained such varied ideas of pothole origin he also seems to have hit upon the true explanation of the normal type for he says, "they seem to be formed by the breaking of the waves, the whirl of the water and currents, which have ground stones and rubbish round inside them."

In North America the idea seems to have prevailed at early dates that the potholes were the work of the aborigines, as is indicated by a quotation cited by Manning:[7]

> General Joseph Sewall in his "History of Bath, Me.," says: "Neither history nor tradition informs us how they [the potholes at Bath, Me.] were made, or for what purpose. By some they are supposed to have been used in the performance of some of the religious ceremonies of the nation. An examination of them seems to leave but little doubt that they were made and used by the natives to boil their food in; so limited was their knowledge of the arts and so rude their implements, that they heated water for cooking by throwing stones into it; the pebbles found in and about these holes are such as would resist the action of heat, and, as if by much use, they are all worn and smooth; and the sides of the holes toward the sea being a little lower than the others, by their smoothness show the effect of the action of the pebbles as they were rolled in and taken out of the excavations."

Similar ideas obtain even now in the western states. Turner[8] describes a large group of glacial potholes in granite in the canyon of the North Fork of Mokelumne river, California, about 30 miles southwest of Lake Tahoe. The locality is known as Harris' Salt Springs. The holes, about 250 in number, are from 6 inches to 6 feet apart. The interiors of all the holes are well-rounded and smooth. They extend over an area of about 2,000 square feet. In this locality salt water oozes from crevices in the rocks and collects in several of the lower holes, the water usually being covered with sodium chloride crystals. Indians are said to have congregated here, attracted no doubt by the salt springs. Many small arrowheads are found near by as are also several small mortar holes such as are used by Indians to grind up acorns. The guides and old settlers acquainted with the vicinity accordingly argue that the holes were made by Indians for the purpose of collecting the salt

[7] Manning, P. C., "Glacial Potholes in Maine," *Portland Soc. Nat. Hist. Proc.*, Vol. 2, Part 5, p. 190, 1901.

[8] Turner, H. W., "Glacial Potholes in California," *Am. Jour. of Sci.*, 3d Series, Vol. 44, pp. 453, 454, 1892.

water in order to bring about the concentration of the salt crystals. While the old settlers did not know personally of any such holes being excavated by Indians, it seemed to them that it would not be difficult for Indians to make the holes by building fires on the granite, allowing the rock to cool and repeating the process a number of times, eventually causing the rock to shell off, meanwhile using such tools as they possessed to facilitate the development of the holes.

In view of these early popular misconceptions of their origin, and since similar ideas are still current in some sections; and further because all types of pothole depressions are not to be explained by any one process, it has seemed worth while to attempt a rational classification of these phenomena on the basis of their mode of formation and then to describe briefly each of the types.

Classification of Pothole Depressions

Class A—Allied types of pothole excavations due to the erosive action of water aided by rock fragments and sediment tools, in the general order of their size from largest to smallest.

1. Moulin potholes or giants' kettles.
2. Plunge pools.
3. Normal potholes.
4. Cupholes and Joint wells.

Class B—Types of pothole-like excavations due primarily to solution.

1. Solution potholes.
2. Dent pits.

Class C—Types of pothole-like excavations of rather uncommon occurrence, due to solution, erosion and other processes acting in combination or singly.

1. Tide pools.
2. Potholes due to sea urchins.

Class A, Type 1:

Moulin potholes (also called glacial potholes) are in general to be correlated with what are popularly termed giants' kettles and are associated in origin with the melting of glacial ice. They have perhaps attracted more attention than any of the other types because of their frequent occurrence away from present stream courses. In some cases no other marks of water action are to be noticed in their vicinity. It is particularly interesting to note that in potholes of this type, according to Upham,[9] "generally the edge or lip of the giants' kettles (moulin potholes), whether large or small, is abruptly cut in the rock

[9] Upham, W., "Giants' Kettles Eroded by Moulin Torrents," *Bull. Geol. Soc. of Am.*, Vol. 12, pp. 40–41, 1900.

surface, perhaps sometimes because of their partial removal at the surface by glaciation subsequent to the moulin erosion." "They seldom have a flaringly curved mouth, such as more frequently characterizes potholes seen at the present time in the process of erosion by cascades in brooks and rivers."

Moulin potholes are commonly very large. Upham[10] describes several in the Interstate Park of the Saint Croix Dalles, Wisconsin, among which is one with a diameter of 27 feet, and another that has a diameter of 15 feet and which has a depth of at least 65 feet. A third occurrence in the same locality has a diameter of 12 feet. The depth of this hole according to Upham[11] is stated by Dr. C. P. Berkey to be 160 feet. The moulin potholes of the "Glacier Gardens of Lucerne" in Switzerland are perhaps the best known. Barker[12] has described two potholes of this type located at Crown Point, New York. It should be noted that glacial potholes are of wide distribution; are apparently coextensive with regions of continental glaciation and are also found adjacent to existing glaciers of the Alpine type. Gilbert[13] ascribes these potholes to the work of a moulin or glacial mill which is a stream of water plunging from the top to the base of a glacier through a well of its own maintenance. The water, which is chiefly derived from ice melting, usually has a short course as a stream on the surface of a glacier before reaching the well, and it escapes from the bottom of the well by a channel under the glacier. The moulin originally forms in a crack or crevasse, and in its initial stage the crevasse must extend from the top to the bottom of the ice mass to admit and transmit the water stream. After a time the crevasse generally becomes sealed by regelation except where the falling water maintains an opening. Thus a vertical fall develops and the stream strikes the rock bed beneath with great force. Boulders and sand are carried by the surface stream to the well and at the base of the ice the plunging water picks up rock fragments and sand from the ground moraine and this material is used as tools with which to attack the rock bed. With long enough continuance of such action a hole is formed which deepens and assumes the character of a normal pothole of very large size.

[10] Upham, W., *Ibid.*, pp. 30, 31.

[11] Upham, W., "Giants' Kettles Eroded by Moulin Torrents," *Bull. Geol. Soc. of Am.*, Vol. 12, p. 31, 1900.

[12] Barker, E. E., "Glacial Potholes at Crown Point, N. Y.," *Jour. Geol.*, Vol. XXI., No. 5, July–Aug., 1913, pp. 459–464.

[13] Gilbert, G. K., "Moulin Work under Glaciers," *Bull. Geol. Soc. of Am.*, Vol. 17, pp. 317–320, 1906.

Because it is self evident that a moulin can not maintain itself for an indefinite period in actively moving ice it seems incredible that such large holes in the bed rock could be ground out in the time available. But it is to be noted that moulins develop primarily at the lower ends of very stagnant and inactive glaciers and, further, that the fall of the water may be of very great height. Thus Lubbock[14] relates that the depth of a moulin on the Finster-Aar glacier was found to be 232 meters. This depth would undoubtedly lead to great force in the fall of the water. The mere impact of the water, however, has very little to do with starting the holes, according to Stone.[15] It is chiefly the stones and sediment rolled about that erode. The falling water develops tremendous swirls at the base and these keep the rock tools in active motion. The moulin potholes of regions of continental glaciation are however thought by Upham[16] to have been formed during an early stage of the glaciation, since during that stage the supply of tools would not be too great, as he says would be the case during the latter part of the glacial period.

Class A, Type 2:

Plunge pools are potholes, in general, of large size, occurring at the foot of a vertical or nearly vertical waterfall. At such sites the velocity of the falling water develops especially great energy in swirling stones at the foot of the plunge, and this results in the grinding out of potholes or plunge pools of exceptional diameter (depending on the volume of the water) and depth (depending apparently on the height of the fall). A large plunge pool occurs at the base of the Canadian side of Niagara Falls. According to Spencer,[17] the depth of this pool is 72 feet. In most plunge pools the water is much deeper than it is in the stream channel on their downstream side. Smaller waterfalls develop plunge pools that quite closely resemble normal potholes. In fact there are practically all gradations from plunge pools to the normal type of pothole formed in existing stream channels. It must not be inferred from this, however, that all potholes in existing stream channels are initiated

[14] Lubbock, Sir John, "The Scenery of Switzerland," Macmillan Co., 1898, pp. 92–93, 122.

[15] Stone, G. H., "The Glacial Gravels of Maine and their Associated Deposits," U. S. G. S. Monograph, 34, pp. 324–326, 1899.

[16] Upham, W., "Giants' Kettles Eroded by Moulin Torrents," *Bull. Geol. Soc. of Am.*, Vol. 12, pp. 25–44, 1900.

[17] Spencer, Dr. J. W. W., "Soundings in Niagara Gorge and under the Falls," *Sci. American*, Vol. 99, Aug. 1, 1908, pp. 76–77.

by waterfalls however small. This fact is illustrated in Fig. 2 which shows quite clearly that a pothole may become a plunge pool.

Class A, Type 3:

Normal Potholes.—These potholes occur in the beds of present day streams or recently abandoned stream courses, in places over which the water has flowed either constantly or during its periods of high volume. If still in the process of formation they must be located directly in the course of the water channel at least during occasional periods of flooding. One of the distinguishing characteristics of normal potholes is the presence of waterworn surfaces adjoining the hole. Normal potholes are described in greater detail below.

Class A, Type 4:

Cupholes have been described by Hudson[18] as little potholes that have been cut, not by pebbles, but by sand and silt swirled about by water currents. They rarely exceed 12 centimeters in diameter and may be cut on very steep slopes of a rock surface. According to Hudson,[19] cupholes are somewhat V-shaped, more strictly speaking,—parabolic in vertical sections. (See Figs. 3, 4, and 5.)

The same author also describes *joint wells*[20]—another type of small depressions that occur along joints in rocks that have suffered glaciation. It is his opinion that *joint wells* (see Fig. 6) were cut by combined solution and silt erosion processes and that they are embryonic moulin-potholes in that they are the work of subglacial streams. Hudson, while describing the *cupholes* as "little potholes"[21] caused by wave and undertow acting on the lake shore, is unwilling to have them classed as a form of *incipient* potholes on the ground that they may never become such. He regards their form as being so different from that of

[18] Hudson, G. H., "Some Items Concerning a New and an Old Coast Line of Lake Champlain," N. Y. State Mus. Bull., No. 133, 5th Rept. of the Director, 1908, pp. 160–162, 1909.

[19] Hudson, G. H., "Joint Caves of Valcour Island—Their Age and Origin," N. Y. State Mus Bull., No. 140, 6th Rept. of the Director, 1909, pp. 170–173.

[20] Hudson, G. H., "Rill Channels and Their Cause," Report of the Vermont State Geologist, 1912, pp. 245–246.

[21] Hudson, G. H., "Some Items Concerning a New and an Old Coast Line of Lake Champlain," N. Y. State Mus. Bull., No. 133, 5th Rept. of the Director, 1908, pp. 160–162, 1909.

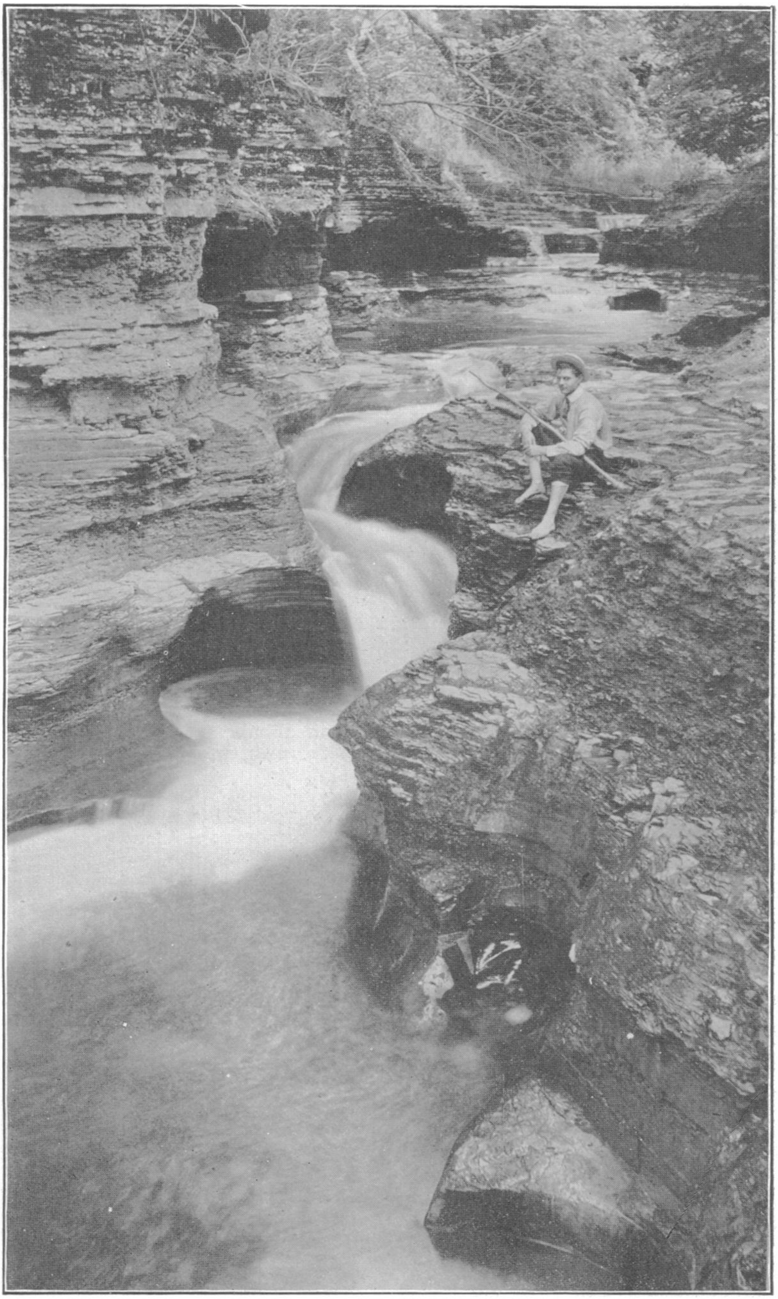

Photo by G. F. Morgan, Ithaca, N. Y.

FIG. 1. INTERSECTING POTHOLES IN GORGE OF BUTTERMILK CREEK NEAR ITHACA, N. Y. Such a series of potholes indicates the primary importance of pothole erosion processes in the deepening of stream gorges.

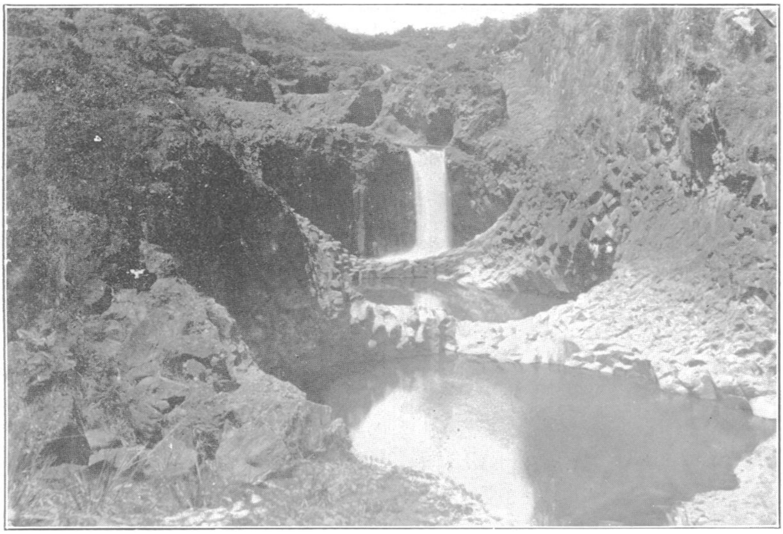

Photo by Libbey.

FIG. 2. SERIES OF PLUNGE POOLS AND A WATERFALL IN LAVA IN HAWAII. Notice how the fully developed pools below the falls have intersected because of enlargement below the water surface thus creating a series of natural bridges. When the pothole at the foot of the falls has developed sufficiently to intersect the base of the similar hollow in the stream bed above, the falls will again retreat and the upper pothole will become a plunge pool. This picture farther illustrates the important part that processes of pothole and plunge pool excavation play in gorge deepening.

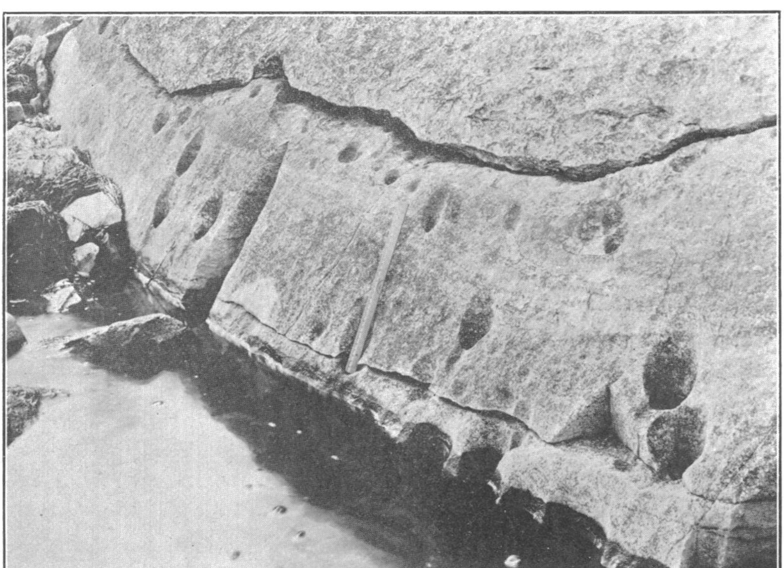

Photo by G. H. Hudson, Plattsburg, N. Y.

FIG. 3. CUPHOLES CUT IN STEEP FACE OF ROCK ON VALCOUR ISLAND.

typical potholes as to entitle them to a name of their own and in a letter to the writer states that they are made by silt and sand carried by vortex motion and that in his opinion the *cupholes* tell of lake conditions or large bodies of water and not of river conditions.

If his interpretation of them is correct, it is possible that the *cupholes* are in origin akin to the so-called tide pools described in another paragraph and hence may be classed as minute forms of normal potholes. Furthermore, it also seems

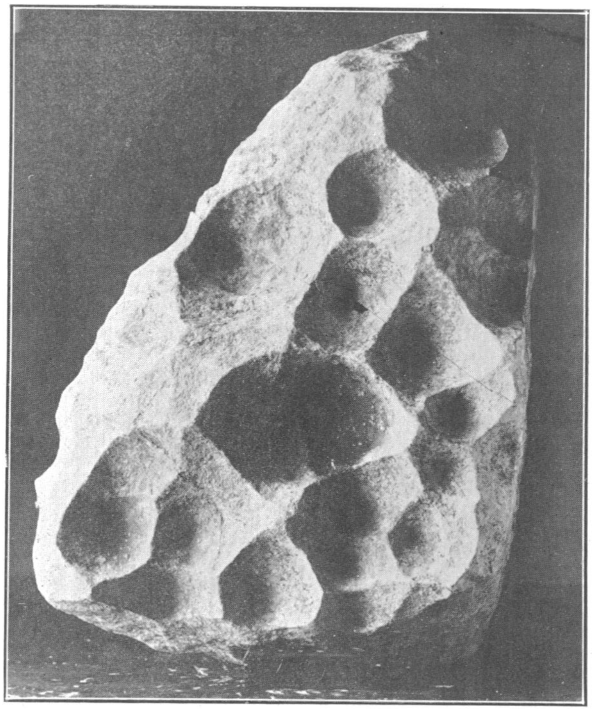

Photo by G. H. Hudson, Plattsburg, N. Y.

FIG. 4. BLOCK OF PURE DOLOMITIC LIMESTONE CUT BY CONFLUENT CUPHOLES. Specimen taken from Valcour Island and is now in the New York State Museum.

probable that the *joint wells* and *dentpits* (a third type of similar small depression) are all very small forms of moulin potholes or solution potholes. Thus the *cupholes* are due primarily to erosive action of fine sediment whirled by the water; the *dentpits* to solution action; while the *joint wells* may be due to both solution and grinding.

Class B, Type 1:

Solution Potholes.—This type includes all the holes that are

formed primarily by solution action. Such holes are most numerous in soluble rocks, notably limestone. They may almost invariably be distinguished from other potholes by the rough solution surfaces of their interiors.

Class B, Type 2.

Dentpits as described by Hudson[22] have been previously mentioned as vortex formed, shallow concavities on rather pure calcareous rock where the water carries but little matter in mechanical suspension. They are due mainly to solution and their width greatly exceeds their depth. The diameters of

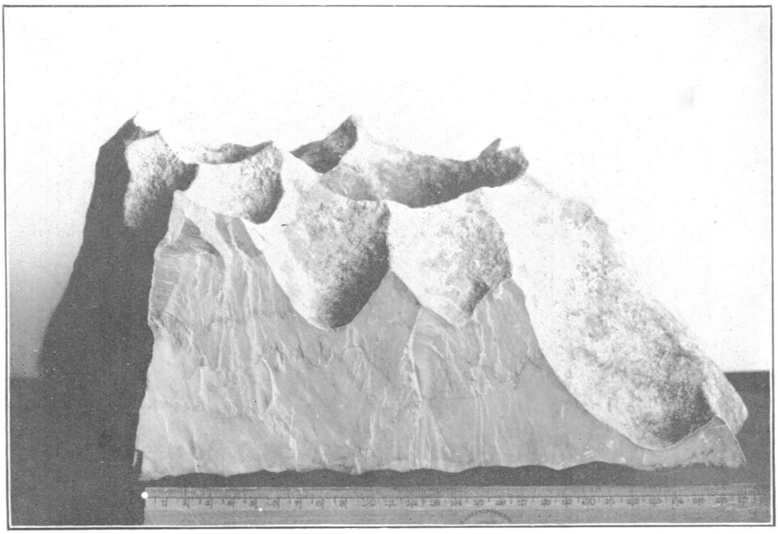

Photo by G. H. Hudson, Plattsburg, N. Y.

FIG. 5. VIEW OF FRACTURED END OF THE LOWER PORTION OF THE BLOCK SHOWN IN FIG. 4. Presents a side view of the cupholes and illustrates parabolic vertical sections of the same. Shows also the edge of the dent-pitted surface below and indicates approximately the quantitative value of the two forms of erosion as geological agents.

dentpits are usually between 1 and 5 centimeters. In vertical sections they present rather circular outlines. No silt is ever found in these depressions which are well shown in Fig. 7.

Class C, Type 1:

Tide pools are a rather uncommon type of pothole depression occurring along rocky coast lines. Their formation seems

[22] Hudson, G. H., "Joint Caves of Valcour Island—Their Age and Origin," N. Y. State Mus. Bull., No. 140, 6th Rept. of the Director, 1909, pp. 165–173, 1910.

to be due to a variety of processes. A particular occurrence of such holes along the west coast of Vancouver Island, near Port Renfrew, B. C., is described and explained by Henkel.[23] The principal rock formations at this locality are, in their order from the surface downward, sandstone, conglomerate and shale. In many places the sandstone has been worn away leaving the conglomerate or the shale as the surface rock. Depressions of varying shape and depth are found in all three kinds of rock but are best developed in the sandstone because of the "extreme softness" of this rock. The pools are also numerous in the shale, but only few occur in the conglomerate. In the sandstone the pools generally occur in strata that are nearly horizontal and they are especially numerous in a gently dipping

Photo by G. H. Hudson, Plattsburg, N. Y.

FIG. 6. JOINT WELLS IN LIMESTONE LEDGE ON VALCOUR ISLAND.

sandstone which contains many concretions. This formation is locally known as the "devil's billiard table." Apparently

[23] Henkel, Isabel, "A Study of Tide Pools on the West Coast of Vancouver Island," *Postelsia*—The Year Book of the Minnesota Seaside Station, 1906, pp. 277, 304.

the concretions have been worn out in many places leaving a depression. The number, size and irregularity of the pools increases with the slope.

The majority of the smaller pools are circular but the larger ones are generally elliptical and give evidence of having been formed by the union of two or more smaller pools. From depressions a few inches in diameter, the size varies to those 30 feet long, 20 feet wide and 10 to 15 feet deep. Plant and animal life is commonly found in many of the pools, notably sea urchins, mussels and barnacles, and in some pools boulders occur that are apparently of the same composition as the concretions. The larger pools, however, contain the fewer boulders.

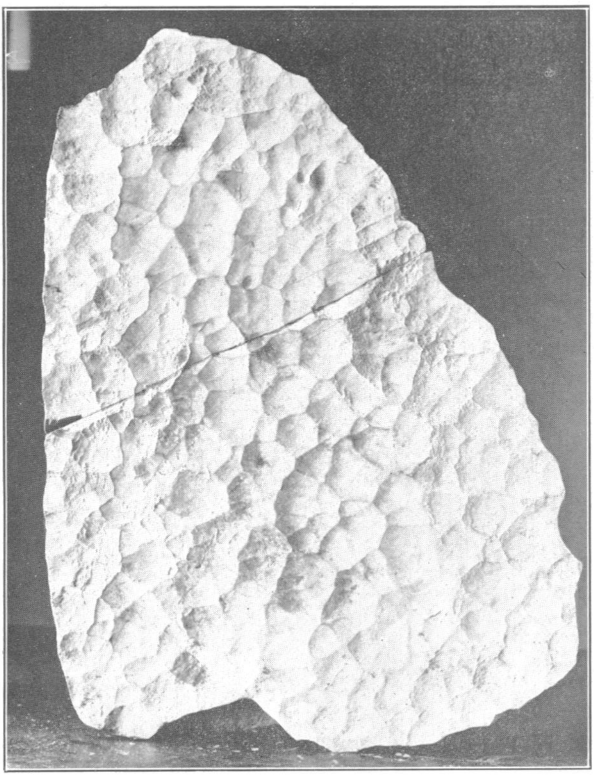

Photo by G. H. Hudson, Plattsburg, N. Y.

FIG. 7. THE UNDERSURFACE OF BLOCK SHOWN IN FIGS. 4 AND 5, SHOWING DENT-PITS. Figure should be viewed at an angle that will eliminate the impression of botryoidal surface.

Henkel considers the occurrence of the concretions to be the most potent factor in the development of sandstone pools. After becoming detached from the formation the concretions

are hurled about inside the depressions gradually enlarging them while at the same time the concretions are reduced in size. This process of enlargement may be aided by plant and animal life exerting a disrupting influence upon the rock. Tide pools in general, however, according to this author are initiated by a variety of conditions and processes, among which may be included: cracks in the rock; concretions; lines of stratification; erosion by waves, tides and wind; action of carbon dioxide; variation in temperature, both of water and of the air; and the action of plants and animals.

Class C, Type 2:

Potholes due to sea urchins are depressions occurring along rocky coast lines and are a type very closely resembling Tide Pools. Such potholes are described by Fewkes[24] who states that they are comparatively rare. Some were found near Grand Manan, New Brunswick, and also at Biarritz, France. They are apparently most commonly found on coasts beaten by a strong sea and in places where there is considerable tidal variation. It seems that the cavities owe their origin primarily to sea urchins, the teeth and spines of which gradually hollow out the depression. Water action rolling these spiny creatures about, and pebbles also apparently facilitates the development of such pools.

(*To be concluded*)

[24] Fewkes, J. W., "On Excavations made in Rocks by Sea Urchins," *The American Naturalist*, Vol. 24, pp. 1–21, January, 1890.